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An active bioindication method for the diagnosis of soil properties using Collembola

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Summary. The active bioindication method was used to examine the effects of acid deposition, from stemflow in a beech forest (Wienerwald), and fertilizing effects in a degraded spruce forest (granite and gneiss highlands) by comparing the population growth and decomposition activity of enclosed Collembola over a six month period. Acids and excessive N-fertilizer lead to delayed population growth and smaller abundances in the test containers. Average abundance of the enclosed collembolans after an investigation period of six months, proves to be a usable indicator of the degree of anthropogenic burden on forest ecosystems.

Key words: Active bioindication, Collembola, soil diagnosis

Introduction

Soil zoological investigations and monitoring coenoses of distressed ecosystems have been main topics of soil ecological investigations during the past years. Anthropogenic burden of acids, heavy metals and excessive nitrogen not only lead to alterations of the soil chemistry, but also to damage to the vegetation and effects on the soil fauna. Sensitive organisms react very clearly to these pollutants. The abundances of some species decrease, while other, less sensitive organisms, gain an advantage due to lack of competition and therefore the community structure of the soil fauna changes. Associated with the reduction in faunal abundance, litter fragmentation is negatively affected and nutrient and energy flow is retarded or interrupted (Kopeszki 1991; Schaefer 1986).
Therefore, an effective way to diagnose soil pollution is to investigae soil coenoses and/or their decomposition activity, and, in this way, the use of animals as bioindictors of soil properties, soil damage and forest decline. This use of zoological criteria like abundance, diversity, and dominance structure is a passive indication of the soil properties.
In a new approach, the active bioindication method, springtails are exposed, in specially adapted microcosms, in different soils. Fertility, growth, development of the populations in the microcosms and decomposition activity associated with the enclosed springtails (*Folsomia candida* Willem and *Heteromurus nitidus* Templeton) are the biological criteria used to describe soil conditions and changes of soil properties caused by anthropogenic burden (Kopeszki 1992b).

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The aim of the present study is first to examine the recently developed active bioindication method for practical use by the investigations of soil properties, and secondly to investigate the effects of manipulations on soil properties with acid (beech stemflow) and different fertilizers on the collembolan populations in the exposed test containers in forest soils.

Materials and Methods

Study Sites

The study was conducted at two sites. The forst was a 100 year old beech forest, northwest of Vienna (Buchen-Wienerwald) at an altitude of 500 m, mean precipitation of 777 mm, mean annual air temperature of 10.3 °C and subject to industrial and traffic pollutants such as acids and heavy metal deposition (Glatzel et al. 1986). The second was an 80 year old degraded spruce forest (Abieti-Fagetum) situated in the northern part of Austria (granite and gneiss highland; Böhmische Masse), at an altitude of 1000 m; mean precipitation of 850 mm, and mean air temperature of 7.3 °C. The soil in the beech wood is a para-brown earth on lime and sandstone, the soil of the spruce forest is an acid raw humus on granite and gneiss (for detailed soil, weather and site descriptions see Katzensteiner 1992a, 1992b).

Beech wood – Wienerwald: Beech trees are characterised by a significant stem flow (about 30 % of the rain runs as stemflow into the soil). The stemflow water in the Vienna woods is contaminated by pollutants, and therefore the soil in the root stock area is enriched with acids (e.g. SO_4-deposition: 96 kg/ha/a), heavy metals (Pb 670 mg/kg soil; Fe 34 g/kg soil) and excessive nitrogen (N-total-deposition: 32 kg/ha/a) (Glatzel et al. 1986). This deposition leads to the formation of a steep pollutant-gradient. In the root stock area the pH is low (pH around 3) but it increases with distance from the stem (e.g. under the canopy the pH is 4). The pollution results in damaged and dying vegetation (so called "dead areas" around the stem) and strongly reduced abundance of the soil fauna, connected with species loss and reduced litter decomposition (Kopeszki 1992a).
Using this gradient the active bioindication method was used in the polluted area under beech trees in three clearly different contaminated plots: the strongly polluted root stock area, the less polluted area in the foliage and between the beech stems (unpolluted soils).

Spruce forest – granite and gneiss highland (Böhmische Masse)

The study was performed in three different plots: an N-fertilized area (1000 kg · ha^{-1} Vollkorn; 15:5:18 + 2,5 = N: P_2O_5: K_2O + MgO + trace elements), "Biomag" – fertilized plot (2000 kg · ha^{-1} basic organic fertilizer: 10 % organic material, 90 % $MgCO_3$), and a control site (for the exact chemical composition of the fertilizer see Katzensteiner 1992a, 1992b; Kopeszki 1993).

Microcosm experiments

The microcontainers (Fig. 1), which were buried in the forest soils, are made of plastic tubes (5 cm high; (∅ 4,8 cm), filled with 1g air dried leaves (*Corylus avellanus*) and 1g wafers, 20 mature collembolans (*Folsomia candida* or *Heteromurus nitidus*), closed with fine meshed gauze, so that the animals could not escape but the (contaminated) soil surface water and soil moisture could run into the containers (Kopeszki 1992b). Thus, pollutants can influence the animals directly or indirectly affect breeding, population growth and decomposition activity. Population growth and decomposition rates should reflect the soil burden and soil degradation by water soluble pollutants.

Fig. 1. Microcontainer with springtails

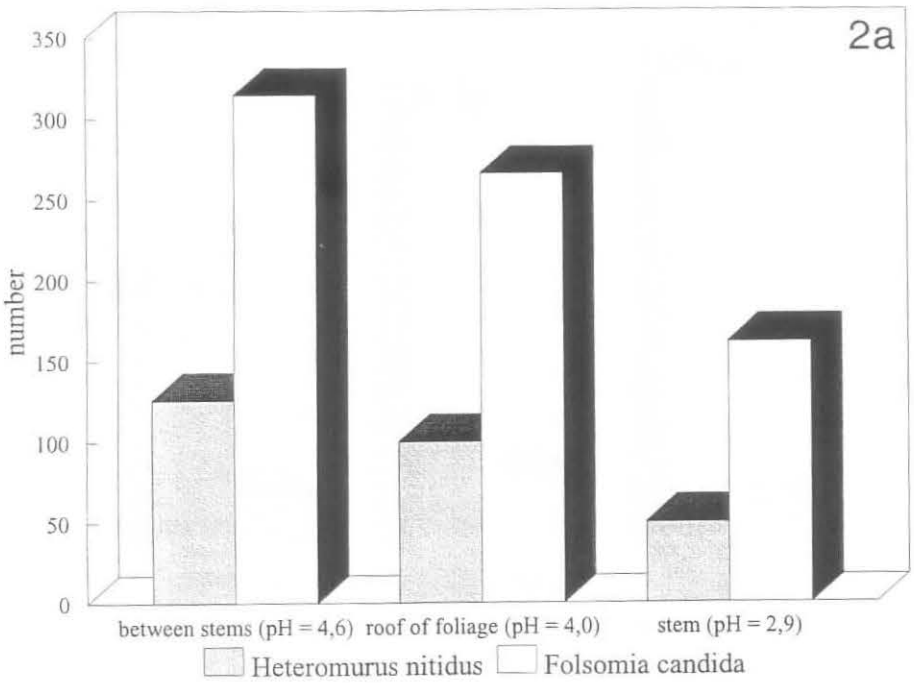
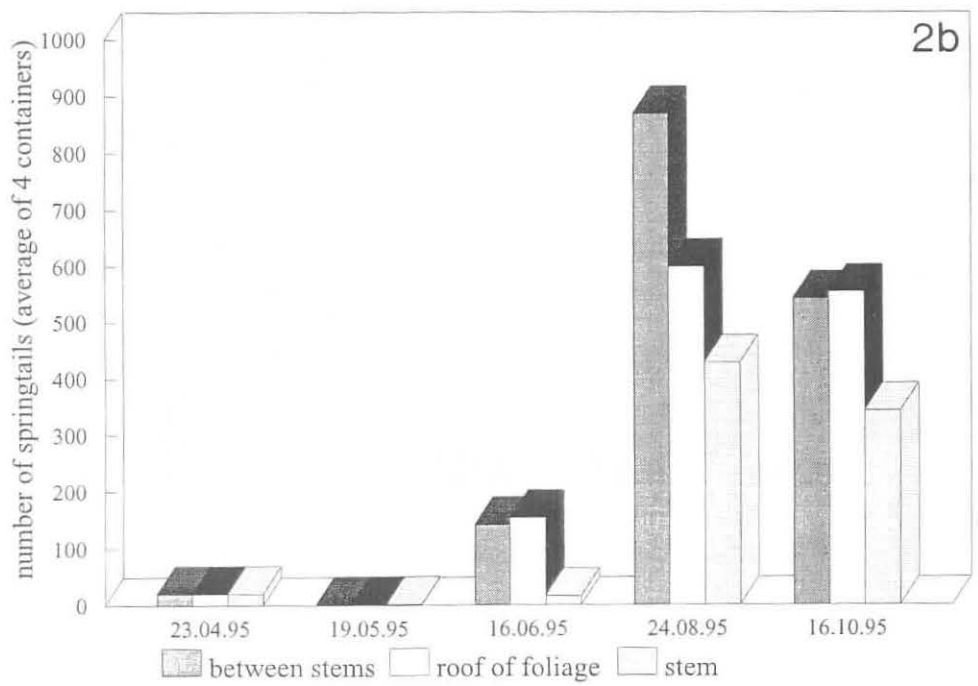
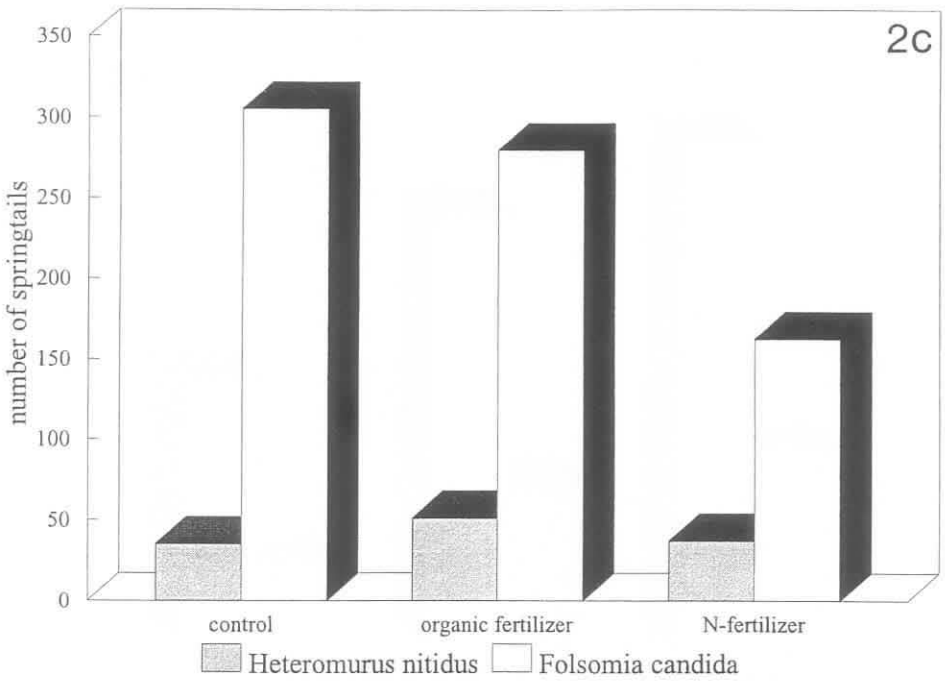
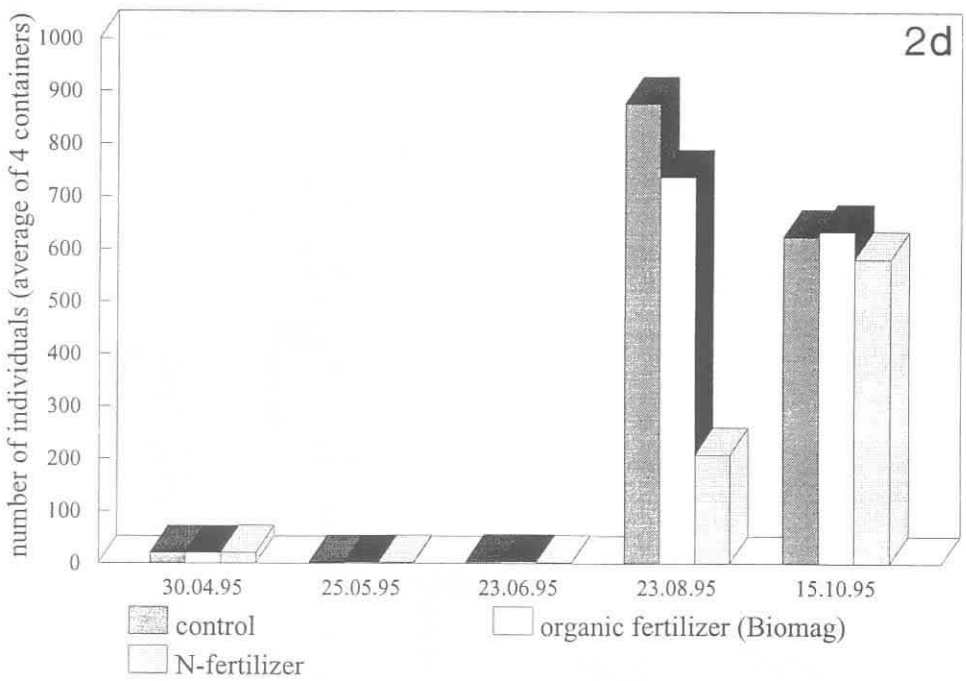


Fig 2a–d. Abundance of springtails in the microcosms (average of six months) in (a) acid stem flow area of a beech tree and (c) in a spruce forest with different fertilization and population dynamics of *Folsomia candida* (starting with 20 individuals per container) in (b) the beech forest and (d) the spruce forest




2c
number of springtails
350
300
250
200
150
100
50
0
control
organic fertilizer
N-fertilizer
Heteromurus nitidus
Folsomia candida


2d
number of individuals (average of 4 containers)
1000
900
800
700
600
500
400
300
200
100
0
30.04.95
25.05.95
23.06.95
23.08.95
15.10.95
control
organic fertilizer (Biomag)
N-fertilizer

In both forests the experiment ran over a six month period (April '95–October '95) and there were four replications at each location within the woods. After four, eight, sixteen weeks and six months exposition test containers were collected. The moisture content, decomposition rate and abundance of the Collembola were recorded. The length of each collembolan was measured and the population dynamics during the experiment determined.

Results

Microcosm conditions

During the first weeks of exposure in both forests a number of the enclosed animals died. This was obviously caused by the sudden change of living conditions (perhaps caused by the lack of microflora on the leaves). Some weeks later, successful breeding started.
The average temperature in the microcontainers exposed in forest soils was about 11 °C, the water content of the enclosed material was 15 % (some days after the beginning of the experiment). The collembolans fed initially on the wafers and later on the leaves. During the six month investigation period, approximately 70 % of the enclosed leaves were eaten by the enclosed animals. The quality and quantity of the enclosed food seemed to be sufficient for both species, they reproduced in the containers and built up large populations independent from soil conditions. In the control plots populations of the parthenogenetic *Folsomia candida* grew to 1000 individuals per microcontainer, while the sexually reproducing *Heteromurus nitidus* reached a maximum of 350 individuals per container. Every manipulation of the soil (with fertilizer or acids) influenced the abundance and population dynamics of the Collembola.

Abundance and population dynamics in the microcosms

Beech forest – acid stemflow investigations
Fertility and population growth of the springtails is clearly negatively affected by the acidity In the extremely acid polluted soils around the beechstem, only small numbers of the animals were found in the containers (Fig. 2a) while in the less contaminated soils (roof of foliage), or in the "uncontaminated" control areas (between stems), the fertility of the animals was higher and the populations in the microcontainers grew larger (Fig. 2b). The pH-value of the soil, population density and decomposition rate in the exposed microcosms are correlated in an almost completely parallel way.
Four months after the beginning, the populations reached their maxima at all sites (in the case of *F. candida* about 1000 individuals per microcontainer, with *H. nitidus* about 320 individuals). In the following weeks of the experiment the populations declined gradually.

Spruce forest – fertilization experiments
The abundance of *F. candida* in the test container is negatively influenced by the two fertilizers, but especially by nitrogen fertilizer. This fertilizer leads to lasting soil acidification and the fertility, growth and decomposition activity of the exposed animals is strongly adversely affected. The basic and organic Biomag-fertilizer leads to a small non significant decline in abundance. *H. nitidus* numbers increase a little but not significantly (Fig. 2c).
By comparing the population dynamics of the two sites (Fig. 2b and Fig. 2d), it can be shown that *F. candida* has similar population dynamics and gain in the control plots of in both forests and that it is not dependent on soil type or altitude. However, *H. nitidus* reached only a mean abundance value of about 120 individuals per microcosm in the beech forest (Fig. 2a) and about 30 individuals per container in the spruce forest.

Decomposition of enclosed leaves

The litter decomposition began immediately after the exposure of the containers. During the six month period in each forest, and at each site the degree of litter fragmentation was similar, and reached about 70 % of the enclosed leaves at the end of the experiment (Fig. 3). No significant differences were found between the two species or two forests.

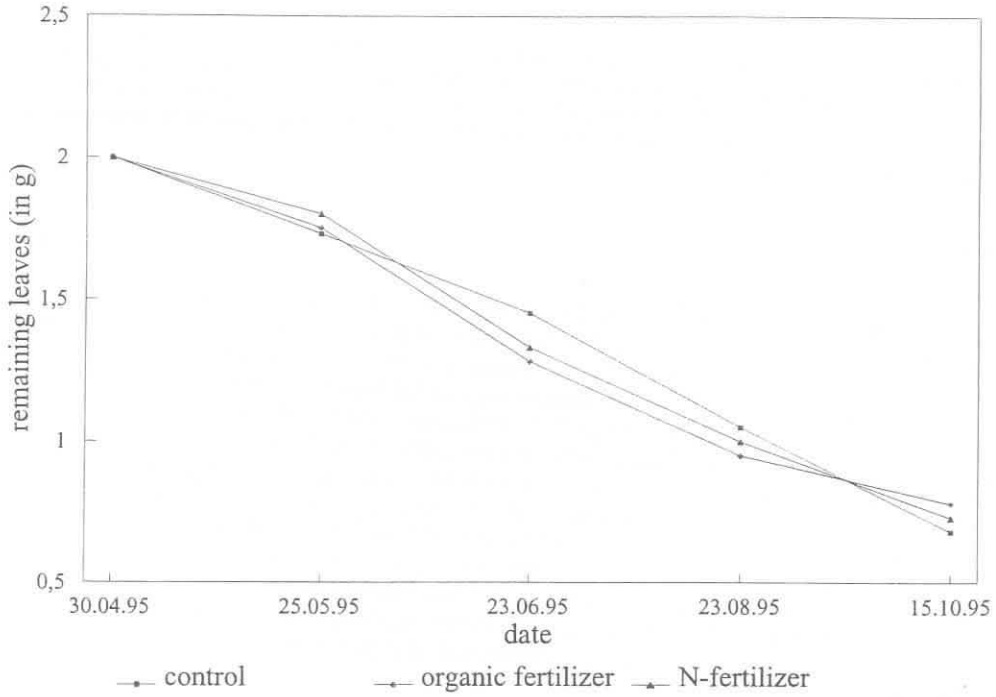


Fig. 3. Litter decomposition in the microcosms with *Folsomia candida*

Discussion

Soil zoological studies are often performed in (European) forests to study the effects of pollution stress such as increased acid or N-deposition on the soil ecosystem and soil fauna (Beck 1989; Funke 1991; Huhta et al. 1986; Schaefer & Schauermann 1990; Schauermann 1988; Van Straalen et al. 1988). Several studies have shown that various soil animals (Arndt et al. 1987; Schubert 1991), like protozoa (Foissner 1987), earthworms (Lohm et al. 1977; Römbke 1989), nematodes (Ruess et al. 1996) and especially Collembola (Dunger 1982; Ghilarov 1980; Hågvar 1982; Kopeszki 1991, 1992a; Kopeszki & Meyer 1994. Van Straalen et al. 1988) could be used as sensitive indicators for soil properties and alterations of soil conditions. But all of these studies use the soil animals as passive indicators.

The recently developed method with springtails is derived from the litterbag method (Crossley & Hogland 1962) and is a further development of the pellets tests (Setälä et al. 1988; Wolters 1991). The difference is that the microcosms of the present study are not placed on the soil surface but buried in the soil. But the important test factor is the exposure of a defined sample of sensitive animals (*F. candida* and *H. nitidus*) under semi-natural conditions to the different sites and soil conditions.

While active bioindication with plants is well known (Schubert 1991), the use of animals, especially Collembola as an active indication has never been attempted. It is well known that the reproduction and development of Collembola is affectedby environmental conditions such as pH, food availibility, temperature and other soil factors (Crommentuijn et al. 1993; Van Amelsvoort et al. 1989; Wolters 1991). While *F. candida* is used frequently in laboratory and microcosm tests (Bakoni & Kiss 1995; Crommentuijn et al. 1993), *H. nitidus* is not so well investigated (Bauer & Christian 1987), but is easy to rear in the laboratory and also in the microcosms.

By comparing the population dynamics of both species, *H. nitidus* seems to be the more sensitive species. It reached, presumably because of its sexual mode of reproduction, relatively low levels of abundance in the exposed microcosms, especially in the spruce forest. *H. nitidus* is therefore more strongly influenced in its reproduction and population development by climatic (the altitude of the spruce forest is 1000 m) and soil conditions (acid raw humus soil).

Several workers have pointed out the negative effect of acidification and incorrect or excessive fertilization on soil animals (Bååth et al. 1978; 1981; Hågvar & Kjondal 1981; Hågvar 1984; Kaupenjohann 1990; Kopeszki 1993; Lohm et al. 1977; Römbke 1989). In the recent active bioindication study the enclosed Collembola are strongly affected by the differences of the soil conditions, mainly influenced by the decreasing (acid stem flow of the beech trees; nitrogen fertliziation of the spruce forest) or increasing (fertilization with basic organic fertilizer in the spruce forest) pH-value. In both cases the abundance has been negatively affected and the population development and population growth retarded. The average abundance of the enclosed collembolans after six months depends very strongly on soil conditions so that this parameter turns out to be the best indicator for considering precisely soil contaminations of forest ecosystems.

During the six month period at each site the degree of litter fragmentation was similar. The ecological parameter "decomposition rate" in the microcontainers seems not to be suitable for soil diagnosis or to report on the degree of soil burden because the fragmentation of the hazel leaves does not depend on the population density of the springtails in the microcosms. These results are contrary to litterbag experiments in beech woods where the decomposition rate depends on the abundance of Collembola (Kopeszki 1991).

Contrary to passive indication a standardized active bioindication method could be used in different soils and could help to solve complex ecological questions. The results from the active investigations are easier to compare because all positive and negative effects of fertilizers, pesticids or acid depositions on the soil biota also affect the enclosed animals and their "biological activity" (reproduction, development, growth, decomposition). Further studies will find out the use of other eventually more sensitive species for this method.

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